A USERS MANUAL FOR BICYCLE-IV:
A COMPUTER CODE FOR CALCULATING LEVELIZED LIFE-CYCLE COSTS

by

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ABSTRACT

This report describes the equations used in the BICYCLE-IV computer code. BICYCLE-IV calculates levelized life-cycle costs for plants that produce electricity.

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I. INTRODUCTION

BICYCLE-IV is a computer code designed to calculate levelized life-cycle costs of electric power generation plants. In addition to total levelized life-cycle costs, the code gives a detailed breakdown of the various life-cycle components that make up the total cost. The code also gives yearly cash flows in current dollars during each year of the plant's lifetime.

Life-cycle costs are calculated using two basic methods that reflect two modes of debt capital repayment. One method assumes that the ratio of outstanding debt capital to outstanding equity capital remains constant. The other method assumes that the debt capital repayment schedule is fixed in advance and that all expenses other than the initial capital investment come from equity capital. This report presents derivations of levelized life-cycle costs for both methods.

BICYCLE-IV is similar to BICYCLE-III but uses Macros, which makes it more versatile and user friendly. It also contains more "help" information. BICYCLE-IV is more flexible. For example, it allows lifetimes for depreciation and debt amortization that are different from plant lifetime. BICYCLE-IV also has a method for calculating return on equity when levelized life-cycle cost is input. However, most of the equations used in BICYCLE-IV are the same as in BICYCLE-III and are described in the following section.

II. METHOD

The costs of producing electricity from a particular plant normally vary during the lifetime of the plant. For example, fuel and labor costs may increase significantly with time, while other components may decrease. The trouble with production costs that vary with time is that it is difficult to compare these costs for competing technologies because there are several numbers to compare. For example, a product from one plant may be more expensive than the product from another plant during one part of its lifetime and less expensive during another part. Therefore, it may be very hard to determine which plant produces the least expensive product over its total lifetime. As a result, levelized (constant) life-cycle costs are usually used for comparing production costs because a single number characterizes each technology.

The underlying principle in computing levelized life-cycle costs is that the income over the lifetime of a project must equal the expenses associated with the project. The income is derived from the revenue received from the sale of the product – in this case, electricity. The expenses include the recovery of the investment, return on the investment, fuel costs, operating and maintenance costs, taxes, and any other expenses related to the project.

Two basic methods of calculating levelized life-cycle costs reflect two methods of debt capital repayment. They are (1) the proportional case and (2) the fixed-payment case. For the proportional case, the debt capital and the equity capital are paid off in a constant ratio. Therefore, throughout the lifetime of the project, the ratio of outstanding debt to outstanding equity is constant. For the fixed-payment case, the entire schedule of debt repayment is fixed in advance. Therefore, any expenses that occur after the start of the project come from equity capital or from revenues.

Projects that are part of an overall corporate financial structure are better represented by the proportional case, which assumes that all funds come from a pool of capital where the ratio of debt to equity is held constant. Single projects that have their own independent debt structure are better represented by the fixed-payment case. Derivations of the expression for levelized life-cycle costs for each method are given below.

A. Derivation of Life-Cycle Costs Using Proportional Debt Repayment

In any year k of a project, a balance sheet can be tabulated. The amount available to reduce the outstanding capital investment in year k is equal to the revenue received in year k minus the expenses in year k. The terms are defined in Table I.

TABLE I. Definition of Terms

	Nonannual Quantities		Annual Quantities
Term	Definition	Term	Definition
e	Equity fraction	I_k	Total investment outstanding at start of year k
i_e	Cost of equity		
b	Debt fraction	I^e_k	Total equity investment outstanding at start of year k
i_b	Cost of dept		
i	Cost of money $= ei_c + bi_b$	R_k	Revenue received at end of year k
		E_k	Quantity of product produced in year k
i'	Tax adjusted cost of money $= i - tbi_b$	oam_k	Operation and maintenance costs for year k
		$fuel_k$	Fuel cost for year k
L	Levelized life-cycle cost	tot_k	Total operating costs for year k
g	Gross revenue tax rate	rev_k	Gross revenue taxes for year k
t	Income tax rate	dep_k	Depreciation on capital for year k
S	Net salvage value	bin_k	Bond interest for year k
K	Project lifetime	A_k	Additional capital investment at end of year k
		cap_k	Annualized capital investment in year k
		bp_k	Bond principal payment for year k

1. Balance Sheet for Year k.

Amount towards reduction of investment in Year k	= revenue in year k	- total operating costs for year k	- return on debt and equity for year k	- (income + gross revenue taxes for year k)

$$= (R_k - tot_k - i \times I_k) - (\text{income + gross revenue taxes for year k}).$$

$$\text{Gross revenue taxes for year k} = \text{gross revenue tax rate} \times \text{revenue in year k}$$
$$= g \times R_k \ .$$

$$\text{Income taxes for} = \begin{array}{c}\text{income tax}\\ \text{rate}\end{array} \times \left(\begin{array}{c}\text{revenue in}\\ \text{year k}\end{array} - \begin{array}{c}\text{deductible expenses}\\ \text{year k}\end{array} \right)$$

$$= t(R_k - tot_k - dep_k - bin_k - g \times R_k)$$
$$= t(R_k - tot_k - dep_k - b \times i_b \times I_k - g \times R_k)$$

Therefore,

$$\begin{array}{l}\text{amount towards}\\ \quad\text{reduction of}\\ \quad\text{investment}\\ \quad\text{in year k}\end{array} = R_k (1 - g) - tot_k - i \times I_k - t[R_k(1 - g) - tot_k - dep_k - b \times i_b \times I_k]$$

$$= R_k(1 - g)(1 - t) - tot_k (1 - t) + t(dep_k) + I_k(t \times b \times i_b - i)$$

$$\begin{array}{l}\text{Investment}\\ \quad\text{outstanding at}\\ \quad\text{end of year k}\end{array} = I_{k+1}$$

$$= \begin{array}{l}\text{investment}\\ \text{outstanding at}\\ \text{beginning of year k}\end{array} - \begin{array}{l}\text{amount towards}\\ \text{reduction of}\\ \text{investment in}\\ \text{year k}\end{array} + \begin{array}{l}\text{additional investment}\\ \text{at end of year k}\end{array}$$

$$I_{k+1} = I_k - [R_k(l - g)(l - t) - tot_k (1 - t) + t \times dep_k + I_k(t \times b \times i_b - i)] + A_k$$
$$= I_k(l + i - t \times b \times i_b) - [R_k(l - g)(l - t) - tot_k (1 - t) + t \times dep_k] + A_k$$

Let

$$i' = i - t \times b \times i_b \ .$$

Then,

$$I_{k+1} = I_k(l + i') - [R_k(l - g)(l - t) - tot_k (1 - t) + t \times dep_k - A_k] \ .$$

2. Balance Sheet for Year 1.

$$I_2 = I_1(1 + i') - [R_1(1 - g)(1 - t) - tot_1(1 - t) + t \times dep_1 - A_l] \ .$$

3. Balance Sheet for Year 2.

$$I_3 = I_2(1 + i') - [R_2(1 - g)(1 - t) - tot_2(1 - t) + t \times dep_2 - A_2]$$
$$= I_1 (1 + i')^2$$
$$- (1 + i') [R_1(l - g)(1 - t) - tot_1 (1 - t) + t \times dep_1 - A_1]$$
$$- [R_2(1 - g)(l - t) - tot_2 (1 - t) + t \times dep_2 - A_2] \ .$$

4. Balance Sheet for Year 3.

$$
\begin{aligned}
I_4 &= I_3(1 + i') - [R_3(1 - g)(l - t) - tot_3\,(1 - t) + t \text{ x } dep_3 - A_3] \\
&= I_1(1 + i')^3 \\
&- (1 + i')^2\,[R_1(1 - g)(1 - t) - tot_1\,(1 - t) + t \text{ x } dep_1 - A_1] \\
&- (1 + i')\,[R_2(1 - g)(l - t) - tot_2\,(1 - t) + t \text{ x } dep_2 - A_2] \\
&- [R_3(1 - g)(1 - t) - tot_3\,(1 - t) + t \text{ x } dep_3 - A_3]\ .
\end{aligned}
$$

5. Balance Sheet for Year K. Because the capital investment is fully recovered at the end of the project (except for the salvage value)

$$
\begin{aligned}
I_{K+1} &= S \\
&= I_K(1 + i')\,[R_K(1 - g)(1 - t) - tot_K\,(1 - t) + t \text{ x } dep_K - A_K] \\
&= I_1(l + i')^K \\
&- (1 + i')^{K-1}[R_1(1 - g)(1 - t) - tot_1\,(1 - t) + t \text{ x } dep_1 - A_1] \\
&- (1 + i')^{K-2}[R_2(1 - g)(1 - t) - tot_2\,(1 - t) + t \text{ x } dep_2 - A_2] \\
&- \ldots - [R_K(1 - g)(1 - t) - tot_K\,(1 - t) + t \text{ x } dep_K - A_K]\ .
\end{aligned}
\tag{1}
$$

Dividing Eq. (1) by $(1 + i')^K$ and rearranging yields

$$
I_1 - \frac{S}{(1+\ i')^K} = \sum_{k=1}^{k} \frac{R_k(1-g)(1-t) - tot_k(1-t) + t \text{ x } dep_k - A_k}{(1+i')^k}
$$

or

$$
\sum_{k=1}^{K} \frac{R_k}{(1+i')^k} = \frac{I_1 - \dfrac{S}{(1+i')^K}}{(1-g)(1-t)} + \sum_{k=1}^{K} \frac{tot_k(1-t) - t \text{ x } dep_k + A_k}{(1-g)(1-t)(1+i')^k}
\tag{2}
$$

Equation (2) is merely a restatement that the revenues over the lifetime of the project (the left side of the equation) must equal the expenses over the lifetime of the project (the right side of the equation). The revenue in year k is equal to the quantity of product produced in that year, E_k, times the price of the product. The levelized life-cycle cost L is defined as follows.

$$
L = \frac{\displaystyle\sum_{k=1}^{K} \frac{R_k}{(1+i')^k}}{\displaystyle\sum_{k=1}^{K} \frac{E_k}{(1+i')^k}}\ .
\tag{3}
$$

When Eqs. (2) and (3) are combined, we get

$$
L = \frac{I_1 - \dfrac{S}{(1+i')^k} + \displaystyle\sum_{k=1}^{K} \frac{tot_k(1-t) + t \text{ x } dep_k + A_k}{(1+i')^k}}{(1-g)(1-t)\displaystyle\sum_{k=1}^{K} \frac{E_k}{(1+i')^k}}\ .
\tag{4}
$$

If we use the algebraic identity,

$$\sum_{n=1}^{N} r^n = \frac{r(1-r^N)}{1-r}\ ,\ \text{then}$$

$$\sum_{k=1}^{K} \frac{1}{(1+i)^k} = \frac{(1+i)^K - 1}{i(1+i)^K}\ .$$

Making use of this identity, the capital investment can be represented as a uniform annual payment over the lifetime K.

$$cap_k = \left[I_1 - \frac{S}{(1+i')^K} + \sum_{k=1}^{K} \frac{A_k}{(1+i')^k} \right] \frac{i'(1+i')^K}{(1+i')^K - 1} \tag{5}$$

When Eq. (5) is substituted in the expression for L [Eq. (4)],

$$L = \frac{\displaystyle\sum_{k=1}^{K} \frac{cap_k + tot_k(1-t) - t \text{ x } dep_k}{(1+i')^k}}{\displaystyle(1-g)(1-t)\sum_{k=1}^{K} \frac{E_k}{(1+i')^k}} \tag{6}$$

If the components included in tot_k are substituted in Eq. (6),

$$L = \frac{\displaystyle\sum_{k=1}^{K} \frac{cap_k + (oam_k + fuel_k)(1-t) - t \text{ x } dep_k}{(1+i')^k}}{\displaystyle(1-g)(1-t)\sum_{k=1}^{K} \frac{E_k}{(1+i')^k}}$$

It is frequently convenient to express the levelized life-cycle cost as a function of each of the following components.

$$L = \left.\frac{\displaystyle\sum_{k=1}^{K} \frac{cap_k + (t/1-t)(cap_k - dep_k)}{(1+i')^k}}{\displaystyle\sum_{k=1}^{K} \frac{E_k}{(1+i')^k}}\right\} \text{capital plus income taxes}$$

$$+ \left.\frac{\displaystyle\sum_{k=1}^{K} \frac{oam_k}{(1+i')^k}}{\displaystyle\sum_{k=1}^{K} \frac{E_k}{(1+i')^k}}\right\} \text{operation and maintenance charges}$$

$$+\frac{\displaystyle\sum_{k=1}^{K}\frac{fuel_k}{(1+i')^k}}{\displaystyle\sum_{k=1}^{K}\frac{E_k}{(1+i')^k}} \quad \Bigg\} \text{ fuel costs}$$

$$+\frac{\displaystyle\frac{g}{1-g}\sum_{k=1}^{K}\frac{cap_k+(oam_k+fuel_k)(1-t)-t\ x\ dep_k}{(1+i')^k}}{\displaystyle(1-t)\sum_{k=1}^{K}\frac{E_k}{(1+i')^k}} \quad \Bigg\} \text{ gross revenue taxes .}$$

B. Derivation of Life-Cycle Costs Using Fixed Payment for Debt Retirement

The derivation for levelized life-cycle costs when the debt repayment schedule is known in advance is similar to the proportional debt retirement case. A key difference is that the calculation of the amount towards the reduction of investment in any given year is for the equity investment only. This is because, by definition, the reduction of the debt investment is already known.

1. Balance Sheet for Year k.

Amount towards reduction of equity investment in year k = revenue in year k - total operating costs for year k - equity return on investment for year k - bond interest for year k - bond principal payment for year k - (income + gross revenue taxes for year k)

$= (R_k - tot_k - i_e \text{ x } I_k^e - bin_k - bp_k)$ - (income + gross revenue taxes for year k).

Gross revenue taxes for year k $= g \text{ x } R_k$

Income taxes for year k $= t(R_k - tot_k - dep_k - bin_k - g \text{ x } R_k)$

Therefore,

amount towards reduction of equity investment in year k $= R_k(1 - g) - tot_k - i_e \text{ x } I_k^e - bin_k - bp_k - t[R_k(1 - g) - tot_k - dep_k - bin_k]$

$= R_k(1 - g)(1 - t) - tot_k (1 - t) - i_e \text{ x } I_k^e - bin_k - bp_k$
$+ t(dep_k + bin_k)$

Equity investment outstanding at end of year k $= I^{e}_{k+1}$

= equity investment outstanding at beginning of year k - amount towards reduction of investment in year k + additional equity investment at end of year k .

$$
\begin{aligned}
I^{e}_{k+1} &= I^{e}_{k} - [R_k(1 - g)(l - t) - tot_k(1 - t) - i_e \times I^{e}_{k} - bin_k - bp_k + t(dep_k + bin_k)] + A_k \\
&= I^{e}_{k} (l + i_e) - [R_k(1 - g)(1 - t) - tot_k (1 - t) - bin_k - bp_k + t(dep_k + bin_k) - A_k]
\end{aligned}
$$

2. Balance Sheet for Year 1.

$$
I^{e}_{2} = I^{e}_{1} (1 + i_e) - [R_1(1 - g)(l - t) - tot_1(1 - t) - bin_1 - bp_1 + t(dep_1 + bin_1) - A_1] \ .
$$

3. Balance Sheet for Year 2.

$$
\begin{aligned}
I^{e}_{3} &= I^{e}_{2} (1 + i_e) - [R_2(1 - g)(l - t) - tot_2(1 - t) - bin_2 - bp_2 + t(dep_2 + bin_2) - A_2] \\
&= I^{e}_{1} (l + i_e)^2 \\
&\quad - (1 + i_e)[R_1(l - g)(l - t) - tot_1(1 - t) - bin_1 - bp_1 + t(dep_1 + bin_1) - A_1] \\
&\quad - [R_2(1 - g)(l - t) - tot_2(1 - t) - bin_2 - bp_2 + t(dep_2 + bin_2) - A_2]
\end{aligned}
$$

4. Balance Sheet for Year K.

$$
I^{e}_{K+1} = S
$$

$$
= I^{e}_{K} (1 + i_e) - [R_K(I - g)(l - t) - tot_K(1 - t) - bin_K - bp_K + t(dep_K + bin_K) - A_K]
$$

$$
\begin{aligned}
&= I^{e}_{1} (1 + i_e)^K \\
&\quad - (1 + i_e)^{K-1} [R_1(l - g)(l - t) - tot_1(1 - t) - bin_1 - bp_1 + t(dep_1 + bin_1) - A_1] \\
&\quad - (1 + i_e)^{K-2} [R_2(1 - g)(1 - t) - tot_2(1 - t) - bin_2 - bp_2 + t(dep_2 + bin_2) - A_2] \\
&\quad - \dots - [R_K(1 - g)(1 - t) - tot_K(1 - t) - bin_K - bp_K + t(dep_K + bin_K) - A_K] \ .
\end{aligned}
\tag{7}
$$

Dividing Eq. (7) by $(1 + i_e)^K$ and rearranging yields

$$
I^{e}_{1} - \frac{S}{(1+i_e)^k} = \sum_{k=1}^{K} \frac{R_k(1-g)(1-t) - tot_k(1-t) - bin_k - bp_k + t(dep_k + bin_k) - A_k}{(1+i_e)^k}
$$

or

$$
\sum_{k=1}^{K} \frac{R_k}{(1+i_e)^k} = \frac{I^{e}_{1} - \dfrac{S}{(1+i_e)^K}}{(1-g)(1-t)} + \sum_{k=1}^{K} \frac{tot_k(1-t) + bin_k + bp_k - t(dep_k + bin_k) + A_k}{(1-g)(1+i_e)^k}
\tag{8}
$$

Solving Eq. (8) for the levelized life-cycle cost L yields

$$L = \frac{I_1^e - \frac{S}{(1+i_e)K}\sum_{k=1}^{K}\frac{tot_k(1-t)+bin_k+bp_k-t(dep_k+bin_k)+A_k}{(1+i_e)^k}}{(1-g)(1-t)\sum_{k=1}^{K}\frac{E_k}{(1+i_e)^k}}$$

If the capital investment is represented as a uniform annual payment over the lifetime K,

$$cap_k = \left[I_1^e - \frac{S}{(1+i_e)^K} + \sum_{k=1}^{K}\frac{A_k}{(1+i_e)^k}\right] \text{ x } \frac{i_e(1+i_e)^K}{(1+i_e)^K-1}$$

then the levelized life-cycle cost can be written as

$$L = \frac{\sum_{k=1}^{K}\frac{cap_k+tot_k(1-t)+bin_k+bp_k-t(dep_k+bin_k)}{(1+i_e)^k}}{(1-g)(1-t)\sum_{k=1}^{K}\frac{E_k}{(1+i_e)^k}}.$$

The capital plus income tax component of the levelized life-cycle cost can be written as

$$\frac{\sum_{k=1}^{K}\frac{cap_k+bin_k+bp_k+(t/1-t)(cap_k+bp_k-dep_k)}{(1+i_e)^k}}{\sum_{k=1}^{K}\frac{E_k}{(1+i_e)^k}}.$$

The expressions for the other components of the levelized life-cycle cost are identical to the expression derived for the proportional case with two important exceptions. First, the discount rate used for the fixed-repayment case is i_e, the return rate on equity. The discount rate used for the proportional case was the weighted cost of money adjusted to take into account the fact that interest on debt is tax deductible. Second, the gross revenue tax expression for the fixed-repayment case is modified to include factors for bond interest and principal payments.

C. Life-Cycle Components

This section is intended to provide additional details regarding the calculation of life-cycle components in BICYCLE.

1. Operation and Maintenance Costs. For this version of BICYCLE, the fixed costs are included with the operation and maintenance costs. The operation and maintenance costs will consist of two types—fixed and variable. Fixed costs are independent of the capacity factor and include such things as property insurance, property taxes, and other fixed costs. The variable cost is of two types. The first type is costs that are proportional to the capacity factor, such as for fuel used to operate the plant. The other type includes one time charges such as expensed capital replacements. As discussed in the input instructions, the user must input these costs for each year. These costs are in inflated (current year) dollars.

2. Fuel Costs. Fuel costs are defined in BICYCLE as the net cost of the raw material that produces the product. For example, fuel costs for a coal generating plant would be the cost of coal. Fuel costs of any coal required by the plant would be included in operation and maintenance costs. These costs are also in current year dollars.

3. Income Taxes. The expression for the calculation of income taxes for year k, shown in Section II, is

(income tax rate) x (revenue in year k - deductible expense in year k)

Depending on the relative magnitude and time dependence of the revenues and expenses, there may be cases where revenues minus deductible expenses could be negative during some years of a project's lifetime. As a result, there may be cases where the income taxes are negative during some years. In fact, there may be some years when the reduction of the capital investment is negative, which means that the total outstanding capital has increased in these years. Of course, the total capital must still equal zero at the end of the project's lifetime (including the salvage value credit).

4. Depreciation Allowance. Two methods of calculating depreciation allowance are included in BICYCLE—straight-line depreciation and sum-of-digits depreciation. The expression for the depreciation allowance dep_k for each method is given below.

$$dep_k = \frac{I_1}{KK} + f_l A_k \quad \Big\} \text{ straight-line depreciation}$$

$$dep_k = \frac{I_1}{\sum_{k'=1}^{KK} k'}(KK + 1 - k) + f_d A_k \quad \Big\} \text{ sum-of-digits depreciation,}$$

where
I_1 = initial capital investment ($),
KK = depreciation lifetime (years).

The terms $f_l A_k$ and $f_d A_k$ are for depreciation of any capital added after the start of the project. This is only for funds that must be capitalized as opposed to being expensed. If capital is added in year k, the added depreciation begins in year k+1, since the capital is assumed to be added at the end of the year. The formulas for these terms are:

$f_l A_k = 0$ for $k \le k_1$

$= \frac{A_k}{K_k}$ for $k_1 < k \le K_k$

$= 0$ for $k_1 + K_k < k < K$

k_1 = the year that the additional capital, A_k, is added to the project
K_k = the depreciation lifetime of A_k
K = the plant lifetime
The term, $f_d A_k$, for the sum-of-the-digits method, is calculated in the same way as the straight line method except that the term $1/K_k$ is replaced by the term

$\dfrac{K_k + 1 - k}{\sum_{k'=1}^{K_k} k'}$ where K_k is the depreciation lifetime for the added capital A_k.

D. Treatment of Inflation

A common error in economic analyses is to improperly mix inflated and deflated parameters. For example, inflated money costs are used with deflated expenses, or vice versa. The general form for the levelized life-cycle cost equation is

$$L = \frac{\sum_{k=1}^{K} \frac{C_k}{(1+j)^k}}{\sum_{k=1}^{K} \frac{E_k}{(1+j)^k}} \tag{9}$$

where

- C_k = expenditures in year k,
- E_k = quantity of product produced in year k,
- j = discount rate, and
- K = project lifetime.

If the expenditures and the interest rate are both inflated parameters, then L is the inflated levelized lifecycle cost. The trouble with such a parameter is that it is difficult to have a "feel" for such a value because it is not in today's dollars. One solution, the use of deflated parameters for both expenditures and the interest rate, gives levelized costs that are in constant dollars. However, income tax effects will result in errors if inflation really does occur.

A more satisfactory solution is to use the following expression.

$$\text{income} = \sum_{k=1}^{K} \frac{E_k L_{in}}{(1+j_{in})^k}$$

$$= \sum_{k=1}^{K} \frac{E_k L_{de}(1+z)^k}{(1+j_{in})^k}$$

where

- L_{in} = inflated levelized cost,
- L_{de} = deflated levelized cost,
- j_{in} = inflated discount rate, and
- z = inflation rate.

Solving this equation for L_{de}

$$L_{de} = \frac{L_{in} \sum_{k=1}^{K} \frac{E_k}{(1+j_{in})^k}}{\sum_{k=1}^{K} \frac{E_k (1+z)^k}{(1+j_{in})^k}} \tag{10}$$

By substituting Eq. (9) into Eq. (10), where inflated parameters are used in Eq. (9), we get

$$L_{de} = \frac{\sum_{k=1}^{K} \frac{C_k^{in}}{(1+j_{in})^k}}{\sum_{k=1}^{K} \frac{E_k (1+z)^k}{(1+j_{in})^k}} \qquad (11)$$

The denominator of Eq. (11) is frequently written as

$$\sum_{k=1}^{K} \frac{E_k}{(1+j_{de})^k}$$

where j_{de} is the deflated discount rate. The expression for j_{de} is given by

$$j_{de} = \frac{(1+j_{in})}{(1+z)} - 1$$

Although this approach gives levelized life-cycle costs in constant dollars (referred to as "price year" dollars), it also takes into account the impact of inflation on income taxes. BICYCLE calculates levelized life-cycle costs in both constant and current, or inflated, dollars.

The deflated levelized life-cycle cost is used by the code to determine the annual revenues. Rewriting Equation 3 and using j_{in} as the discount rate, we have

$$\sum_{k=1}^{K} \frac{R_k}{(1+j_{in})^k} = L_{in} \sum_{k=1}^{K} \frac{E_k}{(1+j_{in})^k}$$

If we assume that the price of electricity increases at the rate of inflation, then

$$R_k = C * (1+z)^k * E_k ,$$

where C is an arbitrary constant.

Using these two equations to solve for C, and using Equation 10, we have

$$C = \frac{L_{in} \sum_{k=1}^{K} \frac{E_k}{(1+j_{in})^k}}{\sum_{k=1}^{K} \frac{E_k (1+z)^k}{(1+j_{in})^k}} = L_{de}$$

Therefore, $\quad R_k = L_{de} * (1+z)^k * E_k$

E. Simplified Solution for Special Case

There is a special simplified case (no summation signs) for computing levelized life-cycle costs that can be used when certain assumptions are made. Even when all the assumptions are not met, this equation can be used for “back of the envelope” estimates. The assumptions that must be made are:

(1) revenue tax = 0,
(2) straight line depreciation is used,
(3) the product output is the same for each year,
(4) no capital is added after the start of the project, ie., all A_k's = 0, and
(5) the expenses are the same for each year, ie. all oam_k's are equal and all $fuel_k$'s are equal,

Since the O & M and fuel costs are assumed constant, this simplified levelized life-cycle cost is really an approximation of the deflated levelized life-cycle cost L_{de}. Therefore, the salvage value used in this case should be deflated.

$S_{de} = S/(1 + z)^K$

With these assumptions, the levelized life-cycle cost for the proportional case is

$$L_{de} = \frac{\sum_{k=1}^{K} \frac{cap_k + (oam_k + fuel_k)(1-t) - t \text{ x } dep_k}{(1+i')^k}}{(1-t)\sum_{k=1}^{K} \frac{E_k}{(1+i')^k}}$$

where $cap_k = \left[I_1 - \frac{S_{de}}{(1-i')^K} \right] \frac{i'(1+i')^K}{(1+i')^K - 1}$

$$L_{de} = \frac{\sum_{k=1}^{K} \frac{cap_k}{(1+i')^k}}{(1-t)E_k \sum_{k=1}^{K} \frac{1}{(1+i')^k}} + \frac{oam_k + fuel_k - t/(1-t) \text{ x } dep_k}{E_k} \text{ x } \frac{\sum_{k=1}^{K} \frac{1}{(1+i')^k}}{\sum_{k=1}^{K} \frac{1}{(1+i')^k}}$$

$$= \frac{I_1 - S_{de}/(1+i')^K}{(1-t)E_k \sum_{k=1}^{K} \frac{1}{(1+i')^k}} + \frac{oam_k + fuel_k - t/(1-t) \text{ x } dep_k}{E_k} \ .$$

Since $\sum_{k=1}^{K} \frac{1}{(1+i)^k} = \frac{(1+i)^K - 1}{i(1+i)^K}$,

$$L_{de} = \frac{i' \text{ x } (I_1 + S_{de}/(1+i')^K)}{(1-t)(1-1/(1+i')^K)E_k} + \frac{oam_k + fuel_k - t/(1-t) \text{ x } dep_k}{E_k} \ .$$

Using the same assumptions for the fixed debt payment case,

$$L_{de} = \frac{\sum_{k=1}^{K} \frac{cap_k + tot_k(1-t) + bin_k + bp_k - t(dep_k + bin_k)}{(1+i_e)^k}}{(1-t)\sum_{k=1}^{K} \frac{E_k}{(1+i_e)^k}} \ .$$

where, for this case

$$\text{cap}_k = \left[I_1^e - \frac{S_{de}}{(1+i_e)^K} \right] \text{ x } \frac{i_e(1+i_e)^K}{(1+i_e)^K - 1}$$

The sum $bin_k + bp_k$ is a constant, $bin_k + bp_k =$ b x i_b x I_1 x (1 + 1/((1+i_b)^K-1))

The term, bin_k is not constant but can be derived.

$$\sum_{k=1}^{K} \frac{bin_k}{(1+i_e)^k} = \frac{i_b \text{x b x } I_1}{(1+i_b)^K - 1} \left[\frac{(1+i_b)^K}{(1+i_e)^K} \text{x} \frac{\left((1+i_e)^K - 1\right)}{i_e} - \frac{1 - \dfrac{(1+i_b)^K}{(1+i_e)^K}}{i_e - i_b} \right]$$

Therefore, for the constant debt payment case.

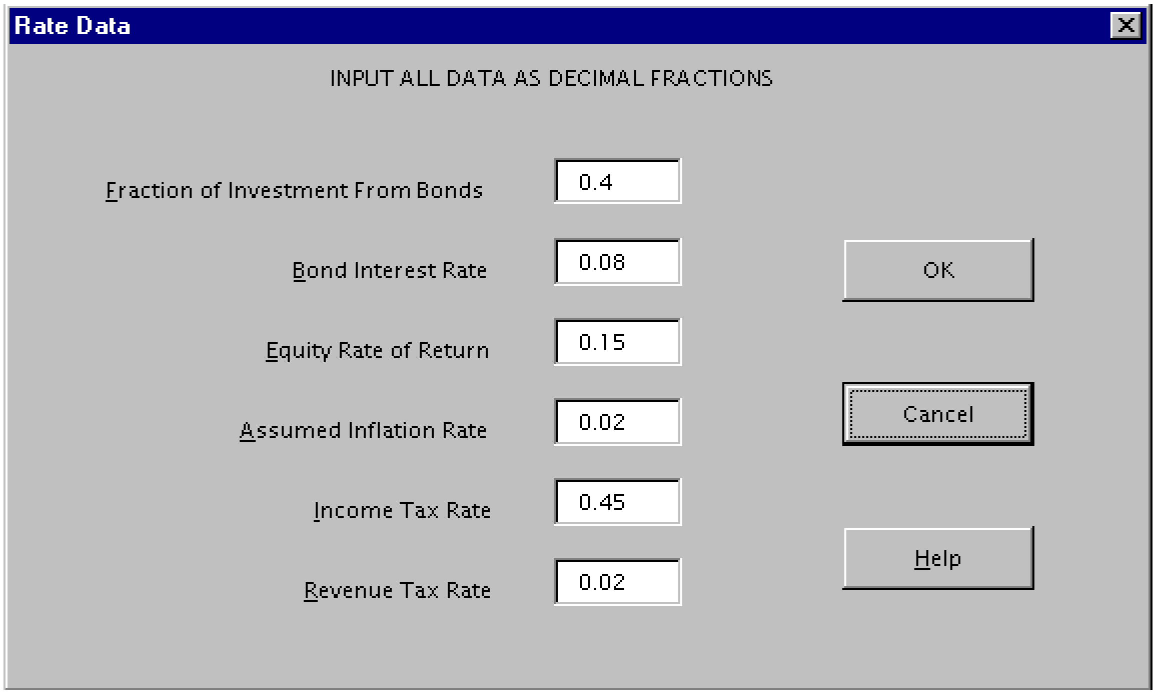
$$L_{de} = \frac{I_1 - S_{de} / (1+i_e)^K}{(1-t)E_k} \left[\frac{i_e(1-b)}{1 - 1/\left(1+i_e\right)^K} + \frac{bi_b}{1-1/\left(1+i_b\right)^K} \left(1 - t + t \left(\frac{1/\left(1+i_b\right)^K - 1/\left(1+i_e\right)^K}{\left(1 - i_b / i_e\right)\left(1 - 1/\left(1+i_e\right)^K\right)} \right) \right) \right]$$

$$+ \frac{oam_k + fuel_k - t/(1-t) \text{ x } dep_k}{E_k}$$

To get an approximation of the inflated life-cycle cost, L_{in}, the inverse of Equation 10 can be used. Starting with Equation 10,

$$L_{de} = \frac{L_{in} \sum_{k=1}^{K} \dfrac{E_k}{(1+j_{in})^k}}{\sum_{k=1}^{K} \dfrac{E_k(1+z)^k}{(1+j_{in})^k}}$$, the value of L_{in} can be derived by rearranging to get

$$L_{in} = L_{de} \text{ x } \frac{\sum_{k=1}^{K} \dfrac{(1+z)^K}{(1+j_{in})^K}}{\sum_{k=1}^{K} \dfrac{1}{(1+j_{in})^K}} = L_{de} \frac{1+z}{1 - z/j_{in}} \left[\frac{1 - \dfrac{(1+z)^K}{(1+j_{in})^K}}{1 - 1/(1+j_{in})^K} \right].$$



III. INPUT INSTRUCTIONS

Data is input into BICYCLE-IV using forms like the above example. The input is very user friendly and the forms and the other input and output sheets have “help “buttons which describe the output and input. Most of the input is similar to the input of BICYCLE-III. However, there is additional life-time data required. There is also a new feature which allows the input of a target levelized life-cycle cost which is then used to estimate the return on equity required to get the target levelized life-cycle cost.

IV. OUTPUT RESULTS

As with the input, the output of BICYCLE-IV is similar to BICYCLE-III. There is more charting capability with BICYCLE-IV and there is an additional output sheet that gives the yearly status of the project capital components. All the results are explained on “help” pages.